Study on the Size Effect and the Effect of the Friction Coefficient on the Micro-extrusion Process

F. Liu, L.F. Peng, and X.M. Lai

School of Mechanical Engineering, Shanghai Jiaotong University, Shanghai 200030, P.R. China
liufang1976@sjtu.edu.cn

Abstract. With the ongoing miniaturization in products, there is a growing demand for the development of accurate forming process for mechanical micro-parts. However, in microforming process, the size effects come up and make the knowledge of the usual forming process can not be used directly. This paper investigates the size effect of H62 with the uniaxial tension experiments, and the results show both the grain size effect and the feature size effect. On the basis of the tension data, the LS-DYNA is used to analysis the micro-extrusion process. The simulation results show that the friction condition affect the microforming process seriously. When the friction condition changes, the stress state of the deformed material also changes. With the increasing of the friction coefficient, the extrusion force increases rapidly.

1 Introduction

In the past decade, the trend towards miniaturization of devices and systems has continued unabated and led to innovative products and applications in industries such as automobiles, health care, electronics, environmental monitoring etc. This trend of size-reduction and increasing functional density in devices has created a need for the fabrication of metallic micro-parts like connector pins, miniature screws, pins for IC sockets and contact springs [1, 2]. A comprehensive review of the field of microforming can be found in the work of Geiger et al. [3].

When the size of mechanical parts are reduced smaller than 1mm, the so-called size effect comes up, which make the know-how, empirical and analytical methods in traditional forming processes can not be used in microforming fields. Several researchers have tried to study the effects of size on material behavior and surface interactions [4-15].

Micro-extrusion is a kind of microforming process which is used widely. This paper studies size effects through the uniaxial tension experiments with the material of H62 and put these data into the commercial FEM code LS-DYNA to investigate the effect of different friction coefficients on the micro-extrusion process.

2 Uniaxial Tension Experiments and Size Effects

The material for the uniaxial tension experiments is H62 wire with different diameter of 0.8mm, 1.3mm and 2.0mm and different grain size of 32μm, 87μm, and 210μm. The

T.-J. Tarn et al. (Eds.): Robot. Weld., Intellige. & Automation, LNCIS 362, pp. 493–499, 2007.
springerlink.com

strain rate is 1mm/s. Fig.1 is true strain-stress curves for specimens with the diameter of 1.3mm and different grain sizes, and Fig.2 is the true strain-stress curves for the specimen with different diameter and same grain size. Figures show that with the increasing of grain size, the flow stress decreases, while with the increasing of the diameter, the flow stress also increases. The material shows both the grain size effect and the feature size effect, but the grain size effect is stronger than the feature size effect.

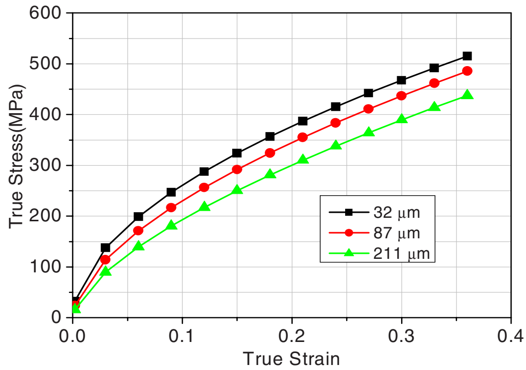


Fig. 1. True strain-stress curves with different gain size (diameter 1.3mm)

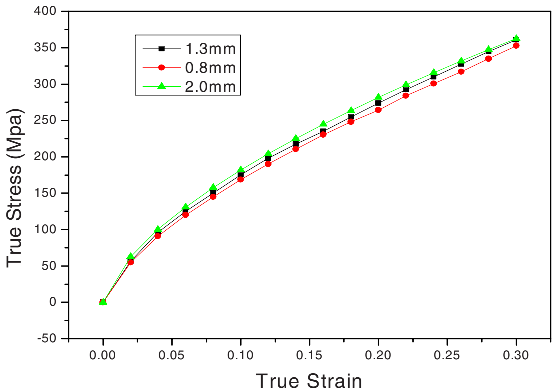


Fig. 2. True strain-stress curves for specimen with different diameter （grain size 211μm）

The decreasing flow stress with the increasing miniaturization can be explained by the so-called surface model [8] (Fig. 3). The grains located at free surface are less restricted than the grains inside of the material. So that it leads to less hardening and lower resistance against deformation of surface grains and makes the surface grains deform easier than those grains inside because dislocations moving through the grains during deformation pile up at grain boundaries but not at the free surface. With the decreasing specimen size and a size invariant microstructure, the share of surface grains increases, which leads to lower flow stress curves.

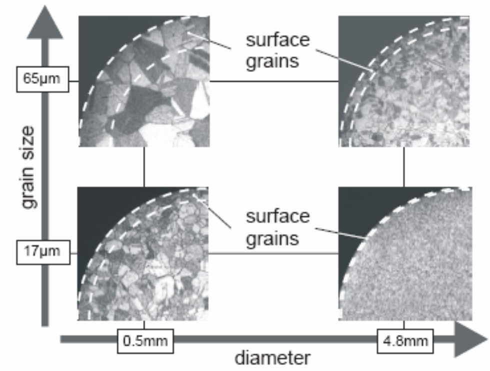


Fig. 3. Surface model of size effects

3 The FEM Model of the Micro-extrusion

In this paper, the LS-DYNA is used to analysis the microforming process, and here we use the uniaxial tension experiment data in section 2 as the material model is. The axisymmetric FEM model is showed as Fig.4, and the extrusion ratio is 5 (10mm/2mm). The punch and die are both rigid body with 184 elements while the deformed billet is separated as 833 CAX4R elements. And the contact arithmetic for the interface between the tool and material is “contact-surface-surface”, and the Column friction model is used.

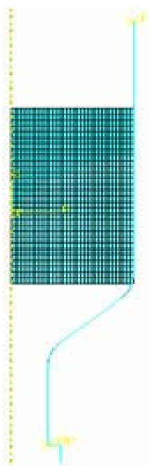
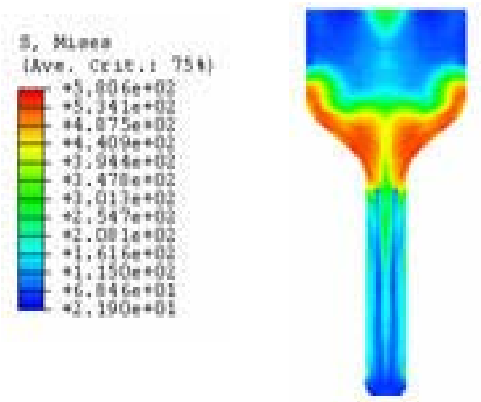


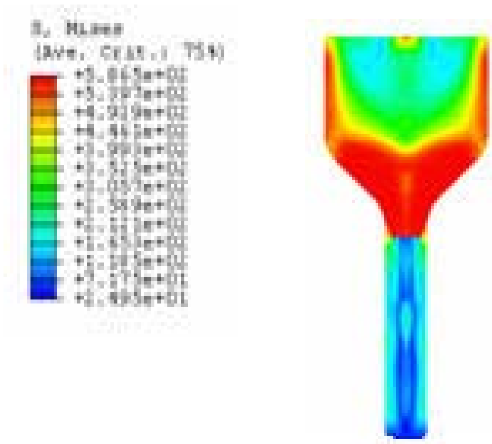
Fig. 4. FEM model for the micro extrusion

4 Results and Discussion

Fig.5 shows the Mises stress distribution of the forward micro-extrusion with different friction coefficient, while the grain size is 211μm. With the increase of the friction coefficient, the Mises stress distribution changes seriously. When the interface between the workpiece and die is smooth, i.e., the friction coefficient is zero, the deformation is comparatively even, only the material nearby the entrance of the female die is deformed very seriously, and at the other area, the stress is very small. When the friction increases, it is difficult for the material which is in contact with the female die to flow because of the friction effect, and at that area, the stress increases obviously. With the

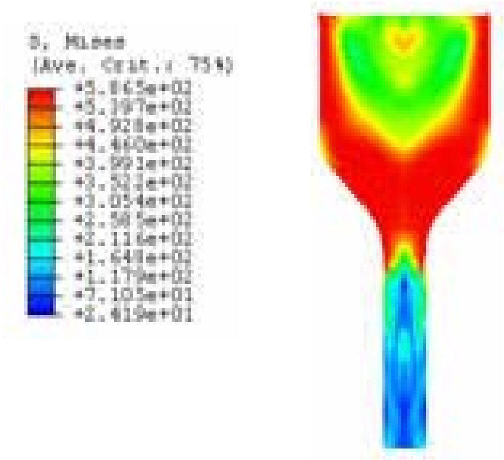


(a) f=0.0



(b) f=0.1

Fig. 5. Mises stress distribution of micro forward extrusion part with grain size of 211μm micron（friction coefficient f=0,0.1,0.2）



(c) f=0.2

Fig. 5. (*continued*)

increase of the friction coefficient, this kind of area also increases, When the friction coefficient is 0.2, it is almost 50% of the whole workpiece. And when the friction is 0.3, it is very hard to carry on the extrusion process. For the H62 with the grain size is 32μm and 87μm, the simulation shows the same rule.

Fig.6 shows the load-displacement curves for the micro-extrusion with the grain size is 211μm、87μm and 32μm respectively. From the figure we can see that, the forward micro extrusion process can be divided into 3 stages. At the first stage, the material fills the whole upper part of the female die and the load increases slowly with the punch moving down, while this stage is a process with small strain and big deformation. At the second stage, the material is deformed seriously and it begins to flow into the lower part of the female die and so the load increases steeply. In this stage, the strain of the whole material is quite huge but the deformation is small. At the last stage, the material flows out of the female die evenly and the load doesn't change seriously.

Fig.7 shows the load–displacement curves for the materials with different grain sizes and friction coefficients. When there is no friction, the load is about 50N, and when the friction increases, the load increases rapidly. When the friction coefficient is 0.1, the load is about 12000N and when the friction is 0.2, the deformation load is about 17000N. The result shows that the friction affects the deformation of the micro-extrusion seriously. Fig.7 also shows that, when the friction coefficient is same, with the increase of the grain size, the deformation load decreases. But comparing with the effect of the grain size, the friction condition affects the extrusion process more, which is due to the increasing ratio of the surface to the volume of the micro-parts. In the micro forming process, the ratio of the surface to the volume of the forming part is much bigger than the ratio of the ordinary part. So during the forming process, the

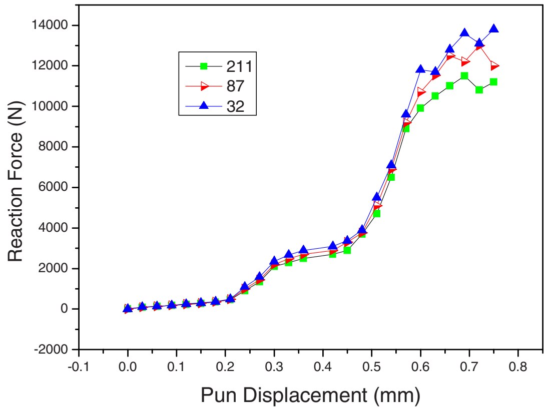


Fig. 6. Extrusion force with punch displacement

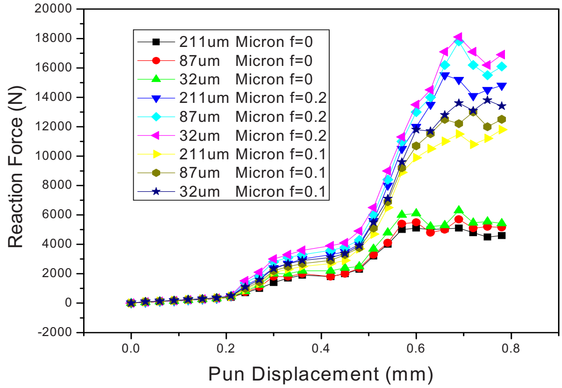


Fig. 7. Extrusion force with punch displacement for different fictional conditions

friction contributes much more to the total deformation load than the ordinary forming process. The smaller the part is, the more seriously the friction condition affects the forming process.

5 Conclusions

(1) The uniaxial tension experiments of H62 with different grain size and different diameters show obvious both the grain size effect and the feature size effect. The flow stress increases not only with the decreasing of the grain size, but also with the increasing of the sheet thickness.

(2) The numerical simulation with LS-DYNA shows that the friction condition affects the micro-extrusion process seriously. With the increasing of the friction coefficient,

the forming load increases rapidly, that is due to the increasing ratio of the surface to the volume of the micro-parts. So comparing to the ordinary extrusion process, the friction force contributes much more to the total deformation load in the micro-extrusion process.

References

1. Neil Krishnan, Jian Cao and Kornel F. Ehmann. Microforming: study of grain size and friction effects in the extrusion of micropins. International Workshop on Microfactory IV, Shanghai, China, Oct. 2004
2. Jian Cao,Neil Krishnan,Zhong Wang,Hongsheng Lu,Wing K. Liu,Anthony Swanson, Microforming: Experimental Investigation of the Extrusion Process for Micropins and its Numerical Simulation Using RKEM, Journal of Manufacturing Science and Engineering, 2004,126:642-652
3. Geiger, M., Kleiner, M., Eckstein, R., Tiesler, N. and Engel, U.. “Microforming”, Keynote Paper, Annals of the CIRP, **50**(2), pp. 445-462. 2001
4. Tiesler, N. and Engel, U., 2000, “Microforming – Effects of Minaturization”, *Metal Forming 2000,* Balkema, Rotterdam, pp. 355-360.
5. Raulea, L.V., Govaert, L.E. and Baaijens, F.P.T., 1999, “ Grain and Specimen Size Effects in Processing Metal Sheets”, Advanced Technology of Plasticity, *Proceedings of the 6th ICTP* Sept. 19-24, **2**, pp. 939-944.
6. Geiger, M., Messner, A., Engel, U., Kals, R.and Vollersten, F., 1995, “ Design of Microforming Processes – Fundamentals, Material Data and Friction Behavior”, *Proceedings of the 9th International Cold Forging Congress*, Solihull, UK, May, pp. 155-163.
7. F. Vollertsen, Z. Hu, H. Schulze Niehoff, C. Theiler. State of the art in micro forming and investigations into micro deep drawing. Journal of Materials Processing Technology. 2002, 151:70-79
8. U. Engel, R. Eckstein. Microforming-from basic research to its realization. Journal of Materials Processing Technology. 2002, 125-126: 35-44
9. Geiger M, Mebner A, Engel E, et al. Metal Forming of Microparts for Electronics. Production Engineering. 1994, 2(1): 15-18
10. WEI Yueguang, Size effect a hard topic for machine- miniaturization, forum for 21 century young scholar: 22(2):57-61
11. Geiger, M.; Meßner, A. , Engel, U. Production of Microparts - Size Effects in Bulk Metal Forming,Similarity Theory. Production Engineering 4 (1997) 1, 55-58
12. L. V. Raulea, A. M. Goijaerts, L. E. Govaert, F. P. T. Baaijens. Size effects in the processing of thin metal sheets. Journal of Materials Processing Technology. 2001, 115:44-48
13. Zhang Kaifeng, Lei Kun. Microforming Technology Facing to the Micromanufacture, China Mechanical Engineering. 2004, 15(12):1121-1127
14. 14. SHEN Yu, YU Huping, RUAN Xueyu. Metal microform technology. Journal of plasticity engineering. 2003, 10(6): 5-8
15. J. F. Michel, P. Picart. Size effects on the constitutive behaviour for brass in sheet metal forming. Journal of Materials Processing Technology. 2003, 141:439-446